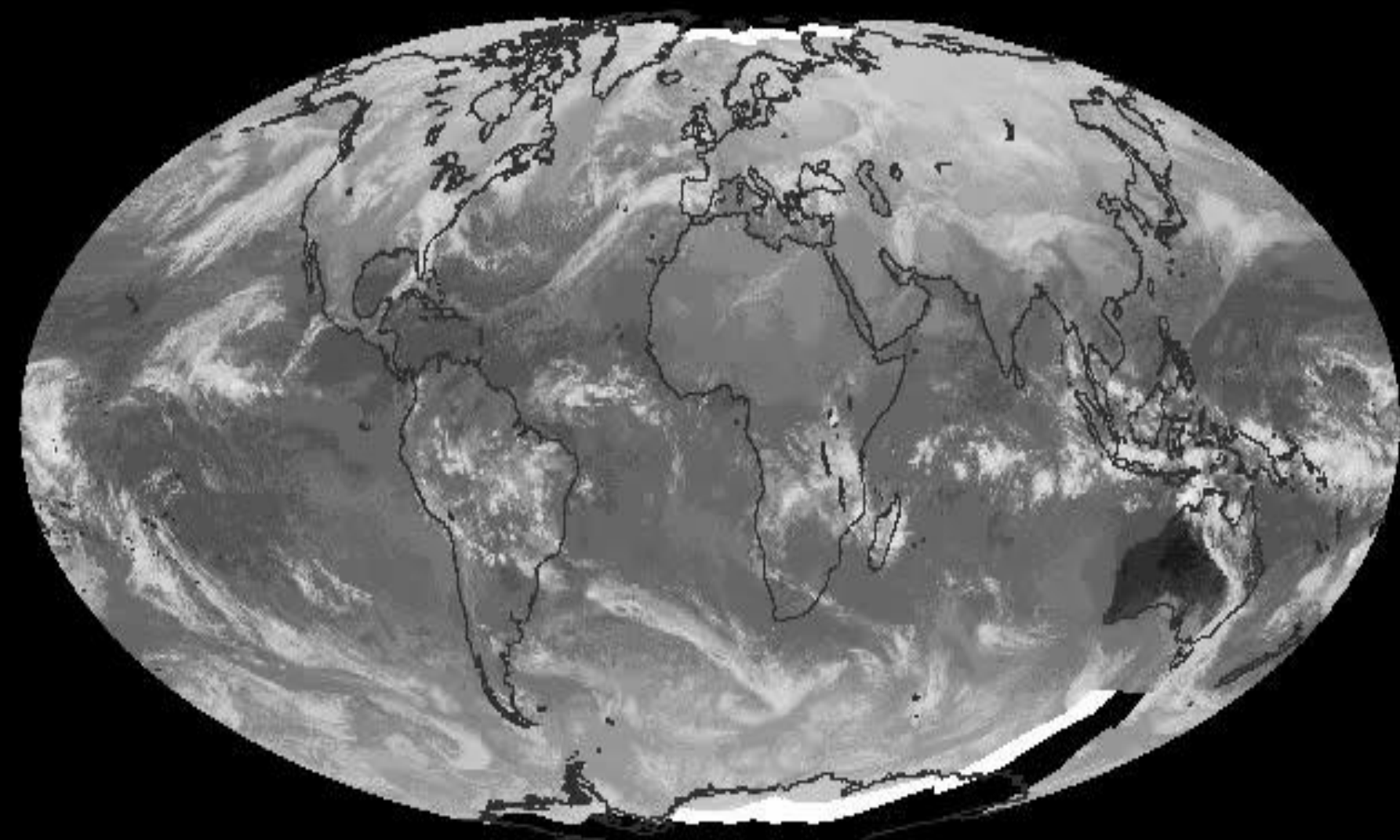


Knowability and no ability in climate projections

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McIDAS

How sensitive is climate to changes in CO₂?

A traditional measure

- *Climate sensitivity* (or *equilibrium climate sensitivity*)

Definition: the long-term change in annual-mean, global-mean, near-surface air temperature to a doubling of CO₂ above preindustrial values

(phew!, e.g., Arrhenius, 1896, Charney, 1979)

- IPCC 2007 says:

Likely (2-in-3)

$$2.0 < \Delta T < 4.5^{\circ}\text{C}$$

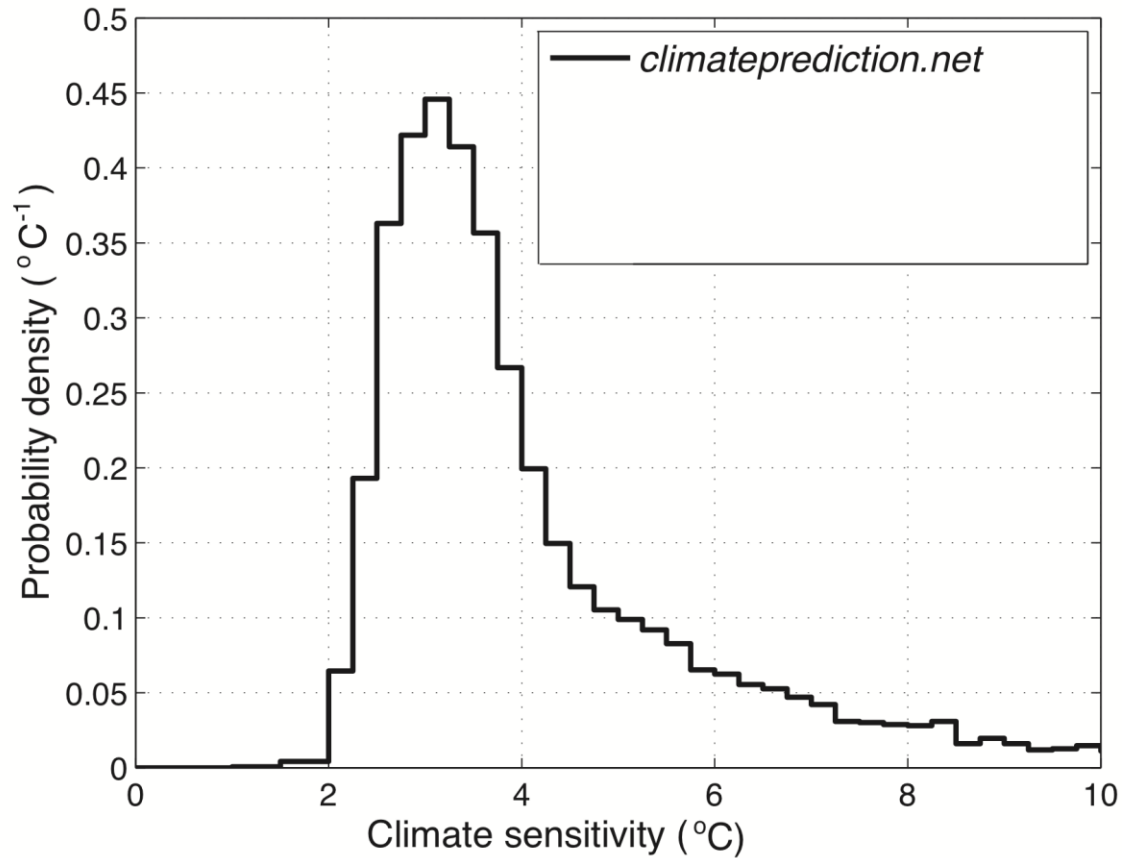
Very unlikely (<1-in-10)

$$\Delta T < 1.5^{\circ}\text{C}$$

- Note this leaves ~2-in-10 chance for $\Delta T > 4.5^{\circ}\text{C}$
(though IPCC says observations are less well fit with these values)

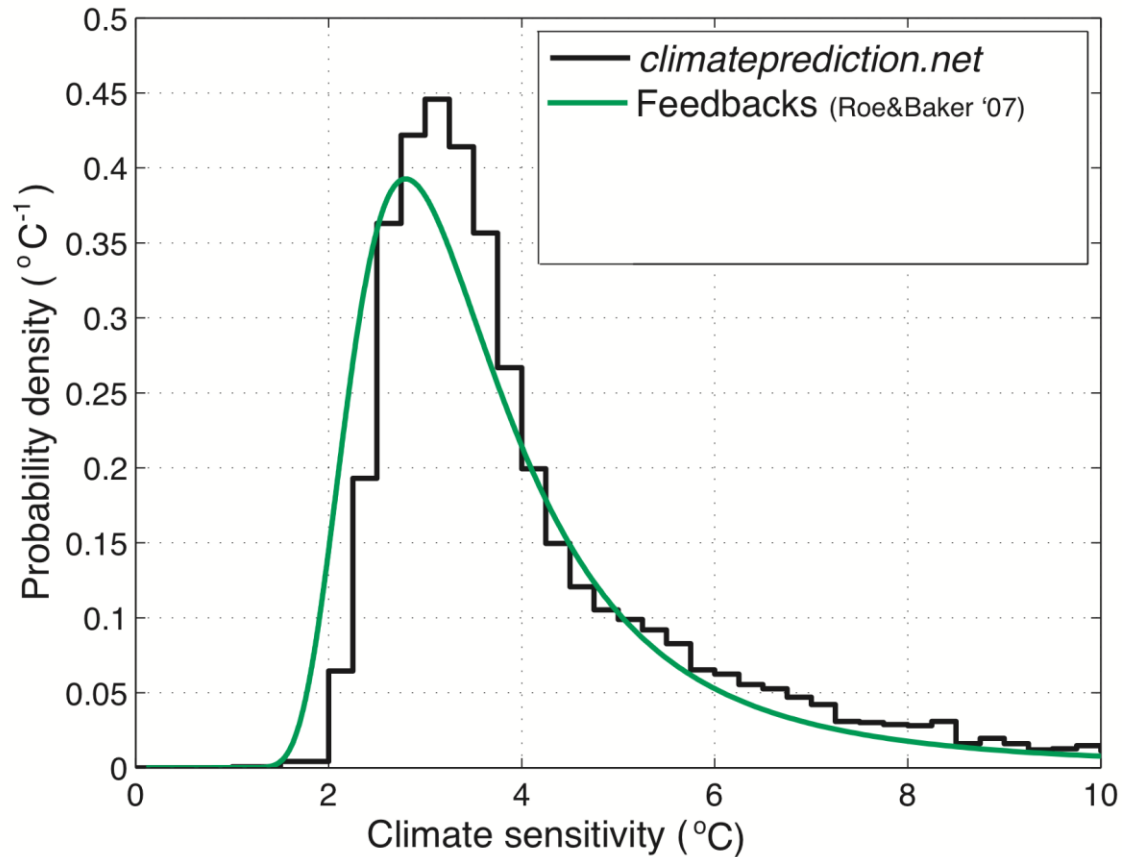
Climate sensitivity

1. Different estimates



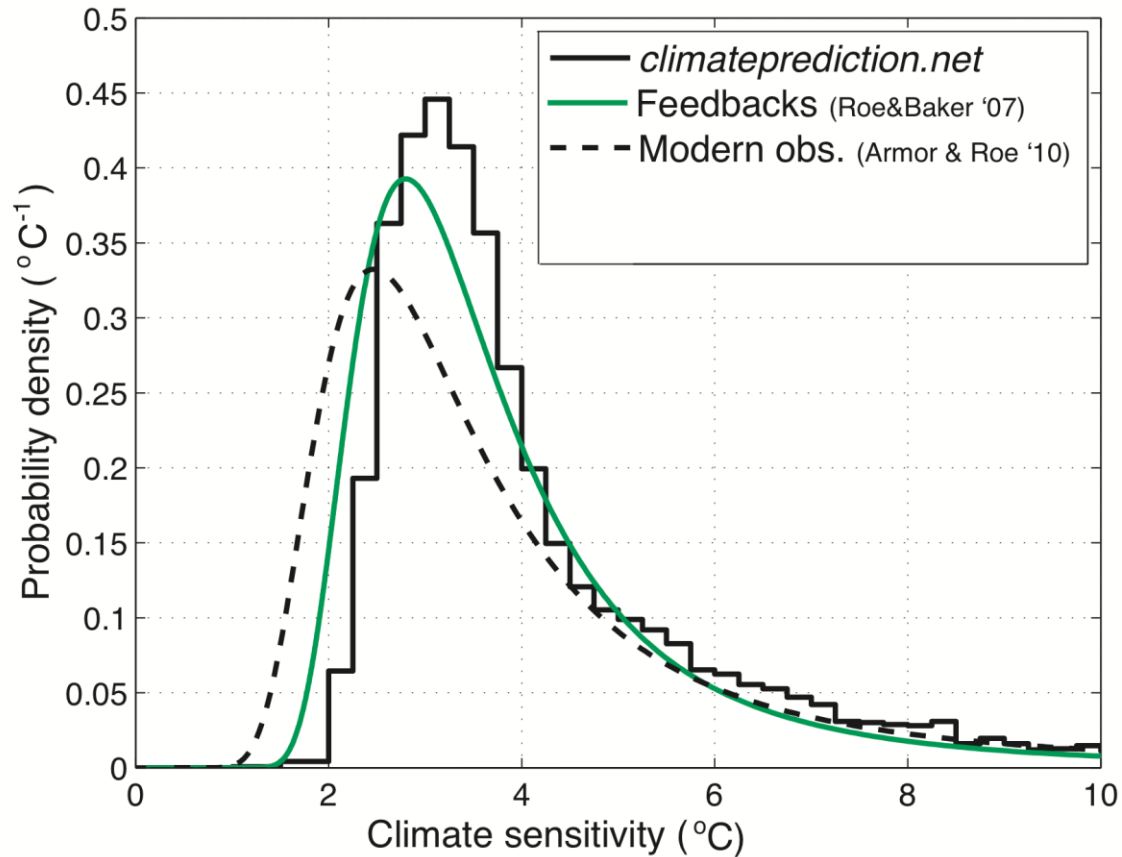
Climate sensitivity

1. Different estimates



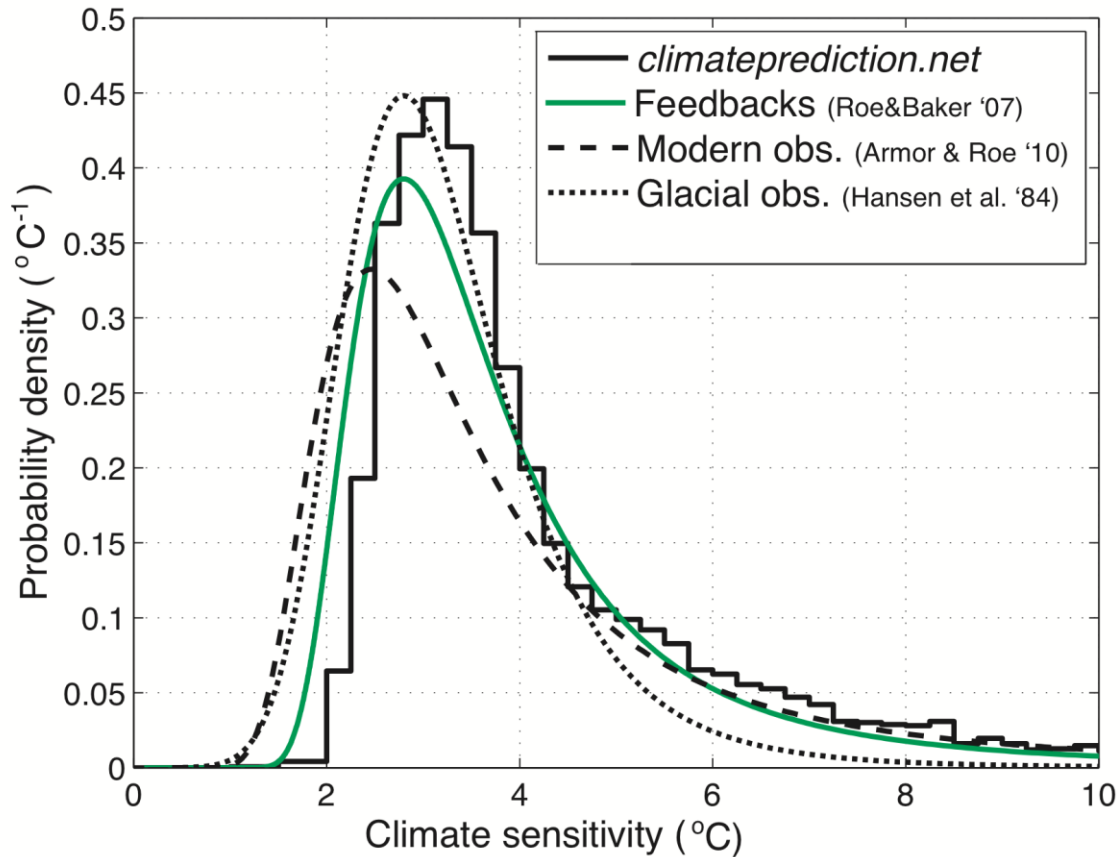
Climate sensitivity

1. Different estimates



Climate sensitivity

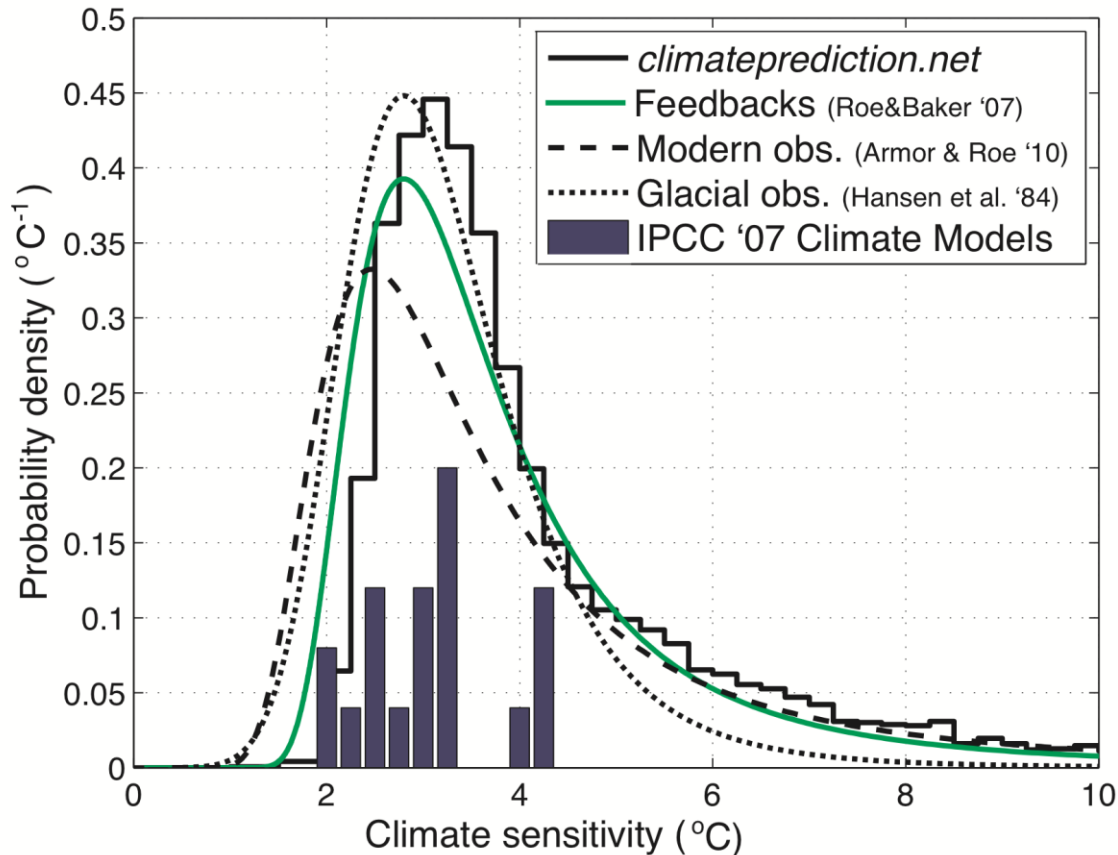
1. Different estimates



So why these values, and why this shape?

Climate sensitivity

1.5 An aside



- The main IPCC climate models under-sample the allowed range.
- An issue for regional climate predictions?

Climate sensitivity

2. Estimates from observations

Global energy budget:

$$\boxed{R_f} = \boxed{F} + \boxed{\lambda^{-1} \Delta T}$$

forcing = storage (ocean) + atmospheric response

In principle, get R_f , F , ΔT from observations, solve for λ , then:

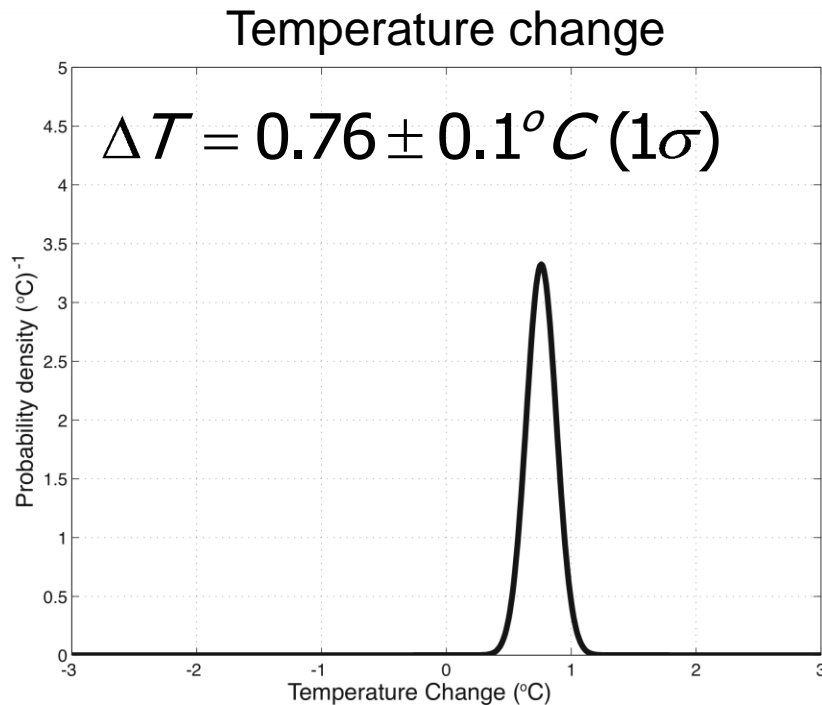
$$\Delta T_{2xCO_2} = \lambda R_{f2xCO_2}$$

$$R_{f2xCO_2} \sim 4 \text{ W m}^{-2}$$

Climate sensitivity

2. Estimates from observations

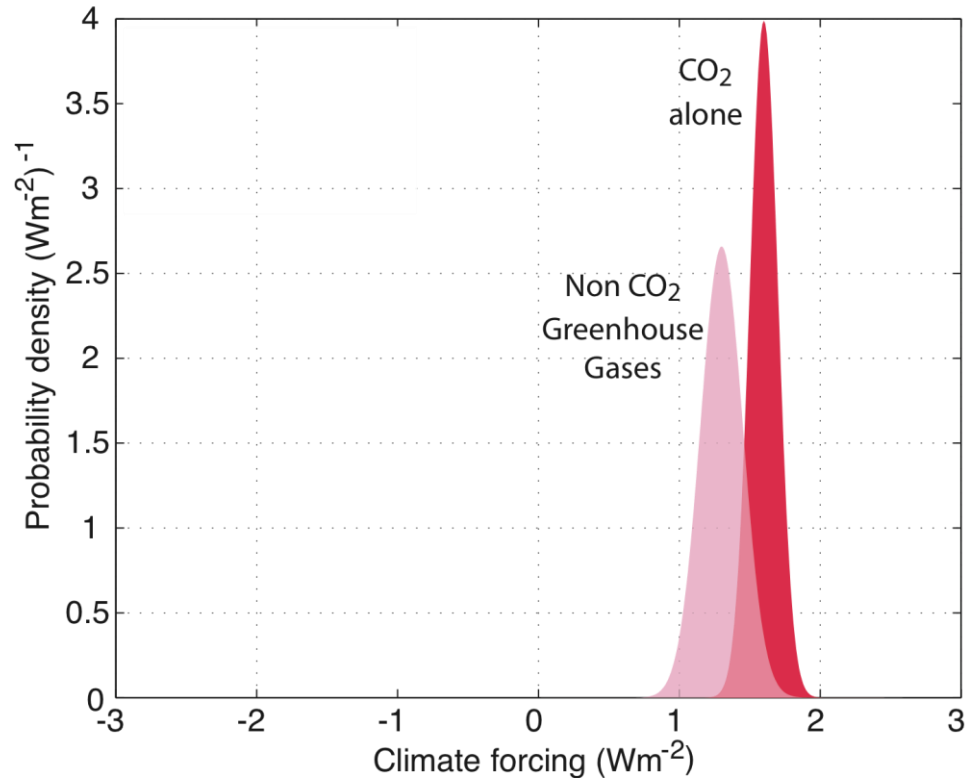
How much warming has there been since pre-industrial times?



- Global mean temperature change is well observed.

Climate sensitivity

2. Estimates from observations

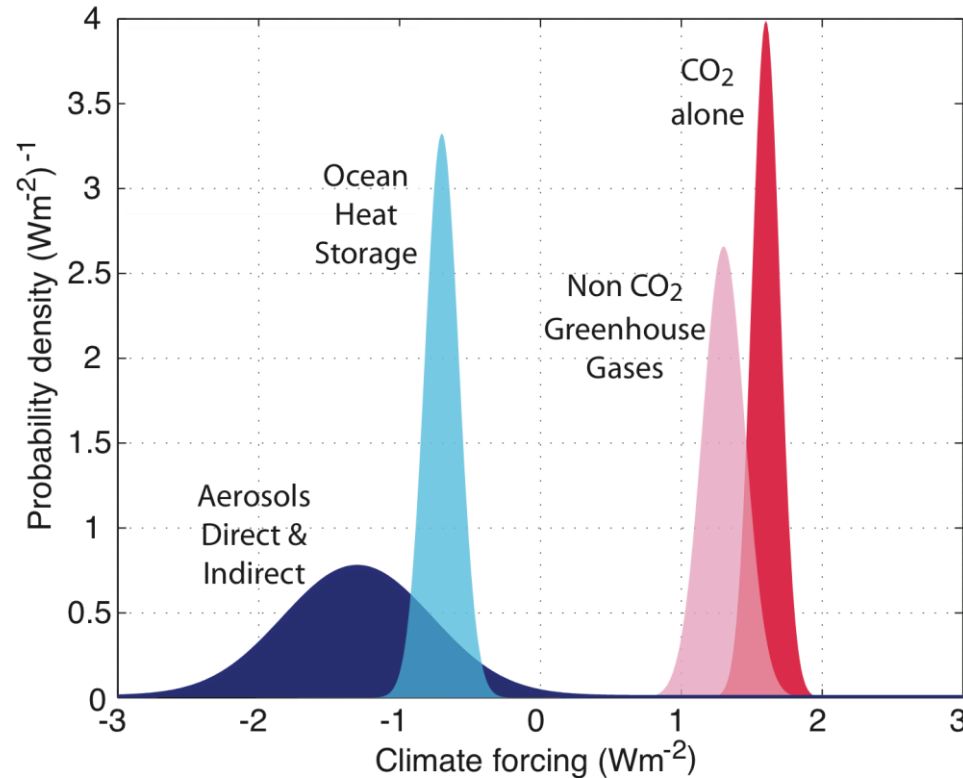


Numbers from
IPCC, 2007

- Warming from CO₂ and other Greenhouse gases (CH₄, O₃)
(plus a tiny bit from solar)

Climate sensitivity

2. Estimates from observations



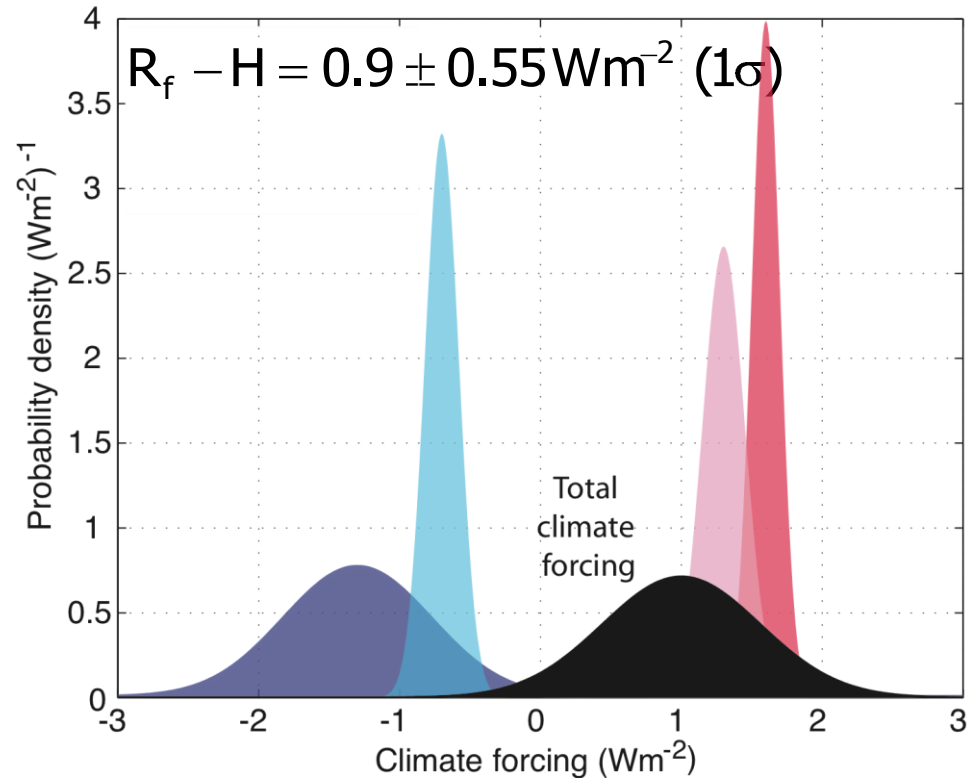
Numbers from
IPCC, 2007
and
Lyman et al. (2010)

- Cooling from heat storage in ocean, and aerosols

Aerosols: airborne particulates (solid/liquid)
have complicated effects (some warm, some cool, change clouds)

Climate sensitivity

2. Estimates from observations

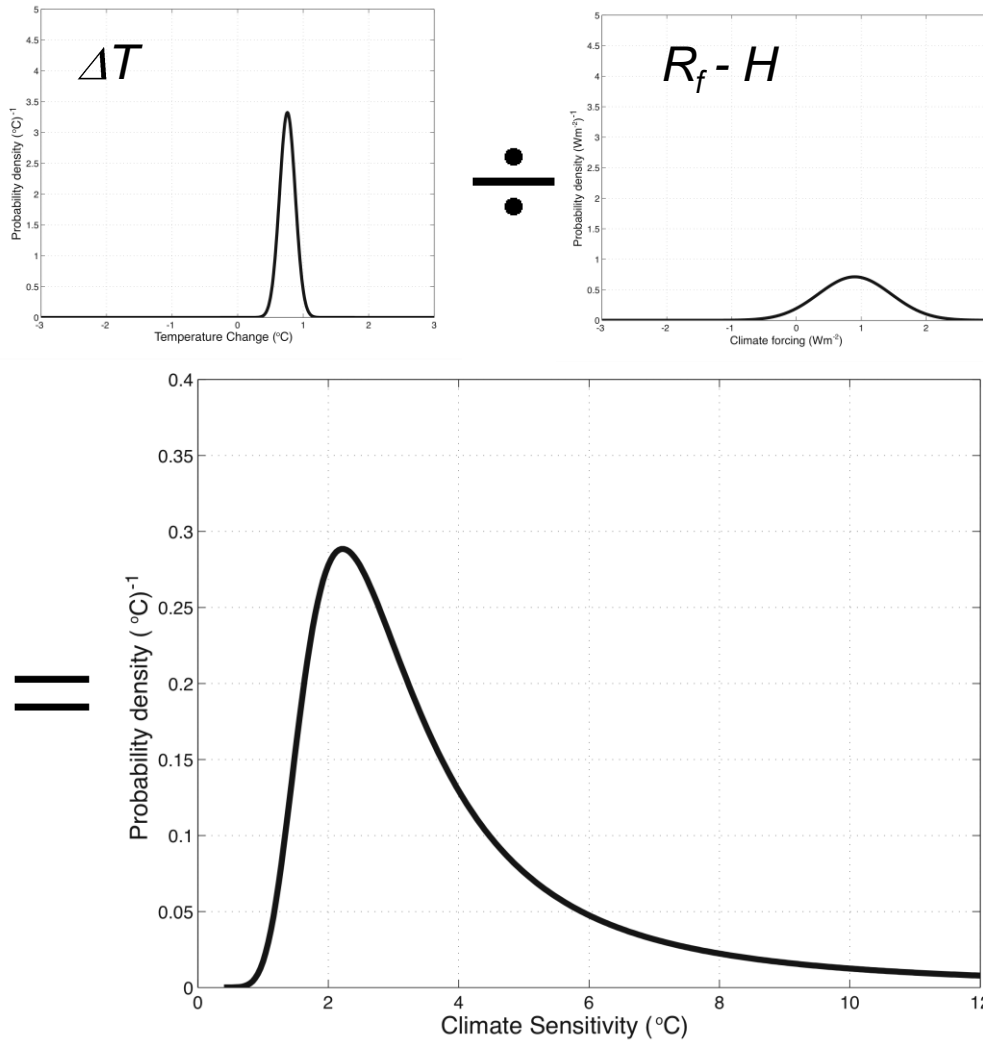


- Total climate forcing is quite uncertain and aerosols are the culprit.

Climate sensitivity

3. Estimates from observations

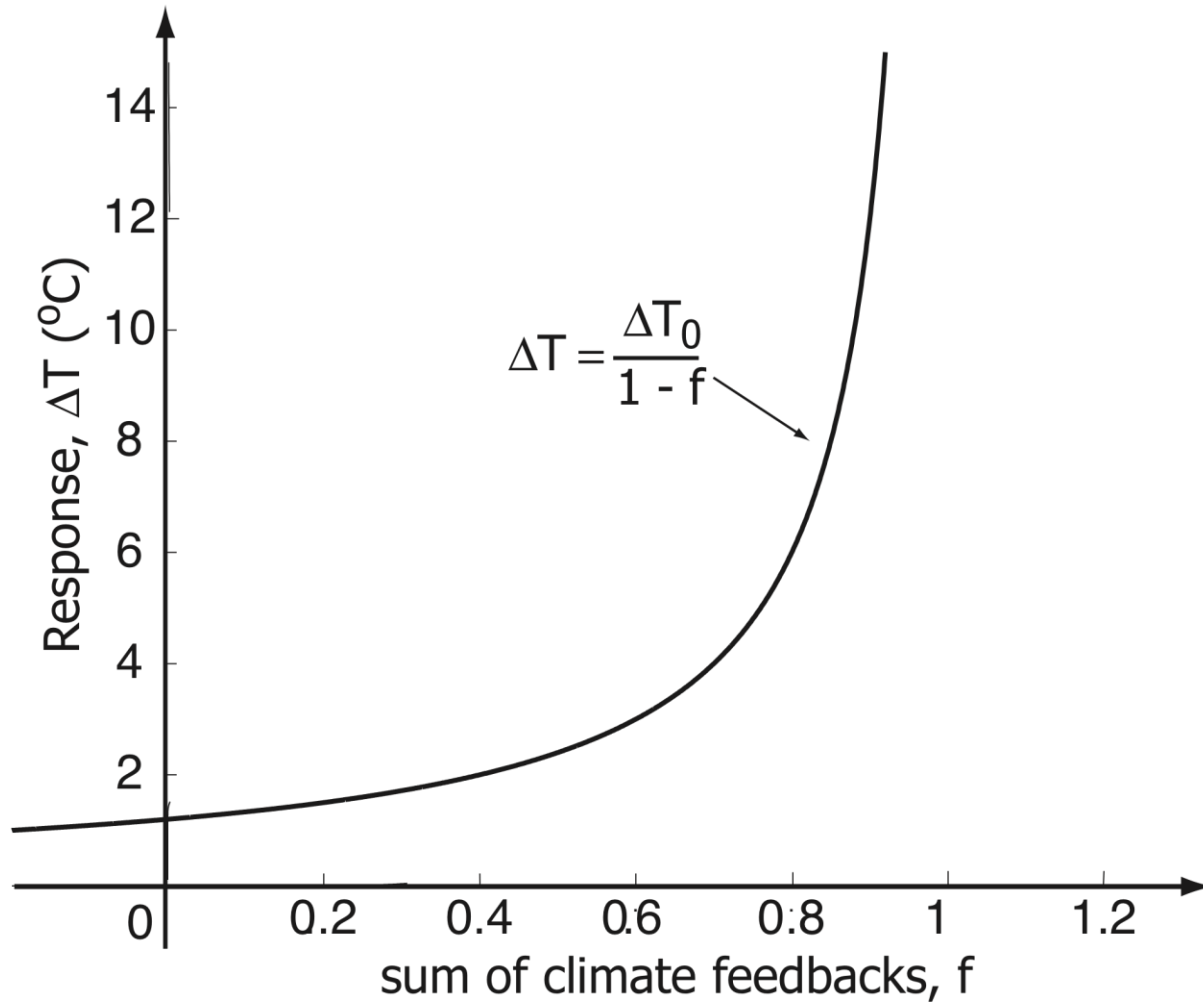
$$\lambda = \frac{\Delta T}{R_f - H}$$



- Fat tail is because aerosol forcing *could* be quite negative

Climate sensitivity

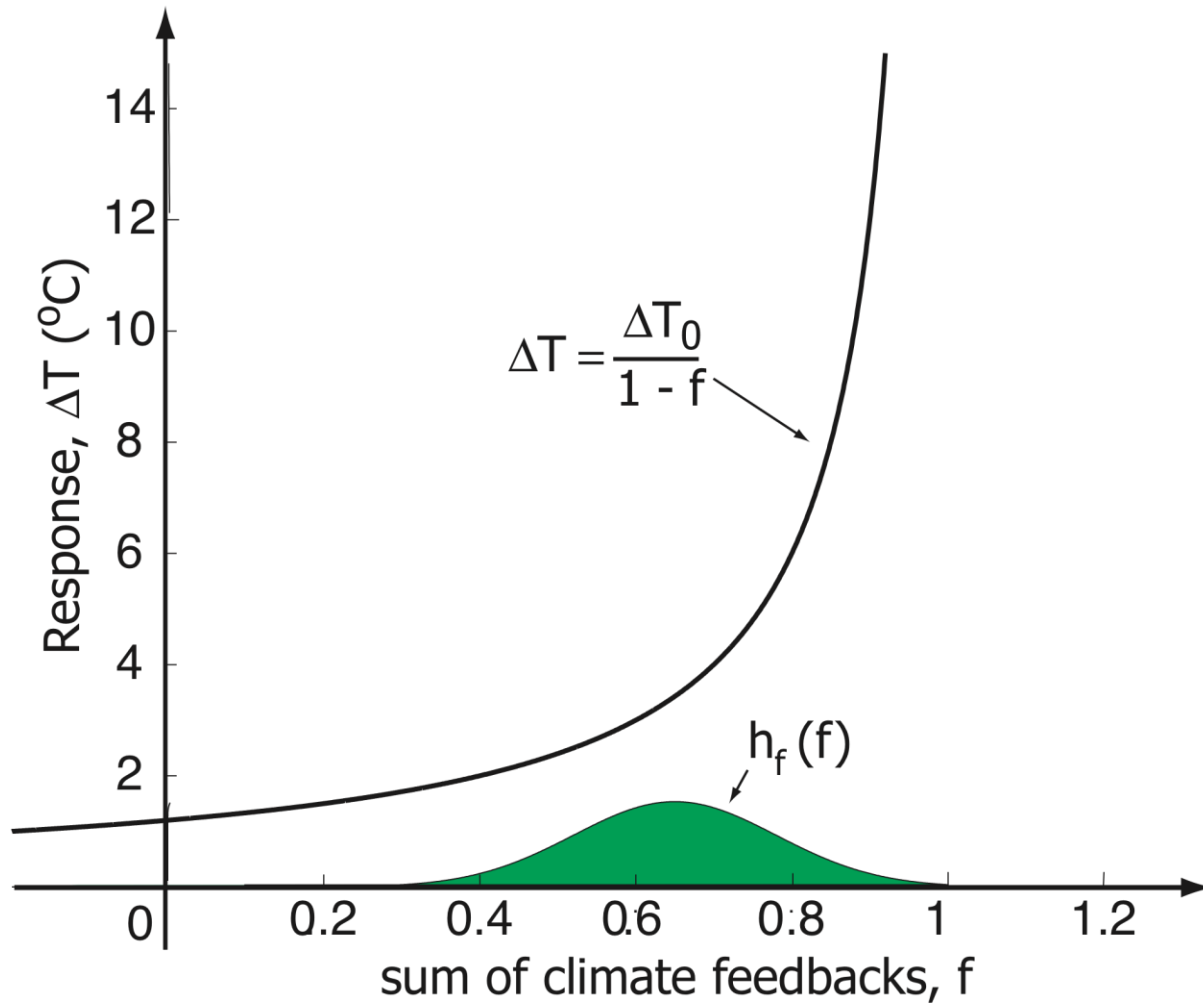
3. Estimates from models



- Black curve is the relationship between climate feedbacks and climate sensitivity.

Climate sensitivity

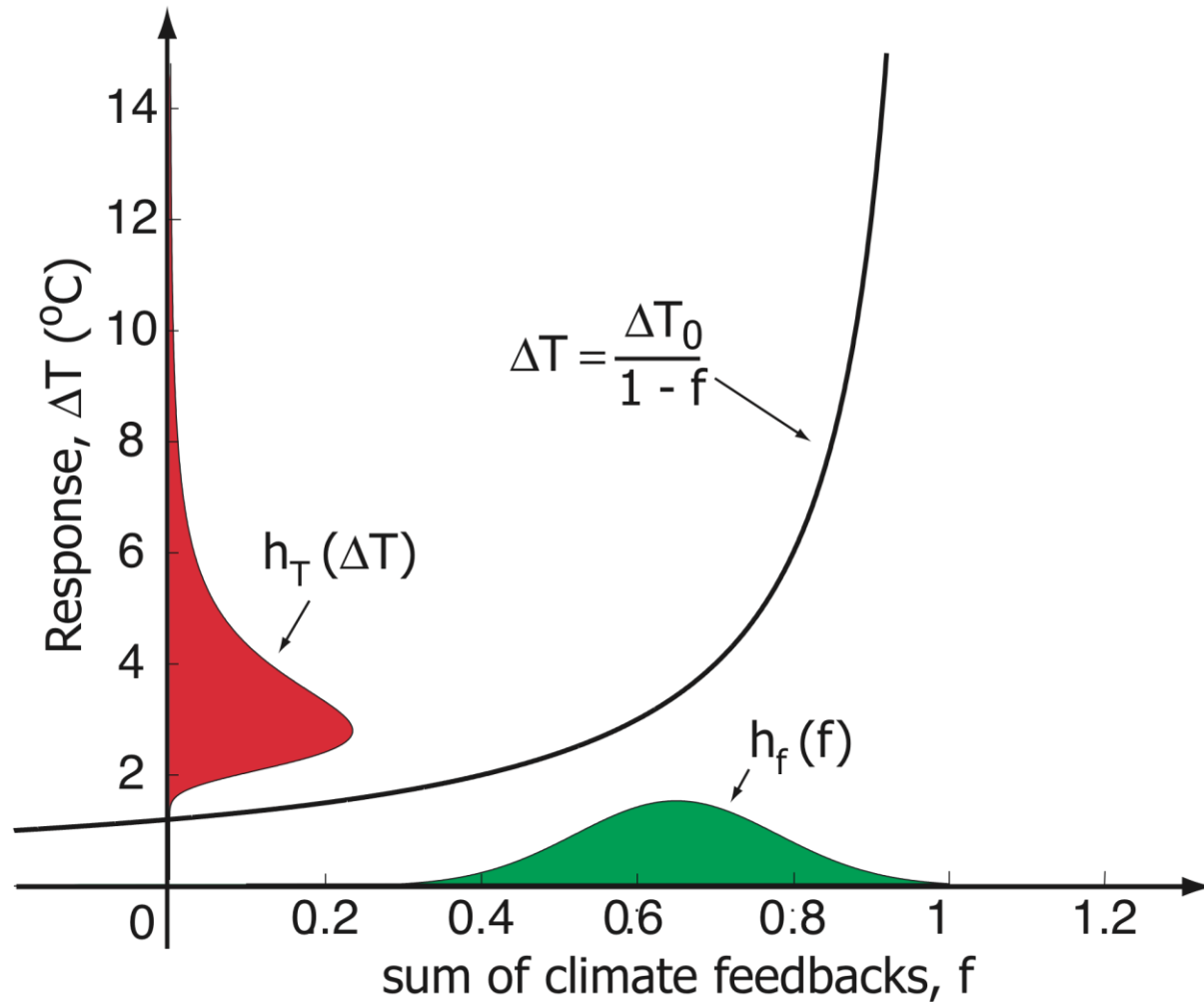
3. Estimates from models



- Green curve reflects current uncertainty in climate feedbacks.

Climate sensitivity

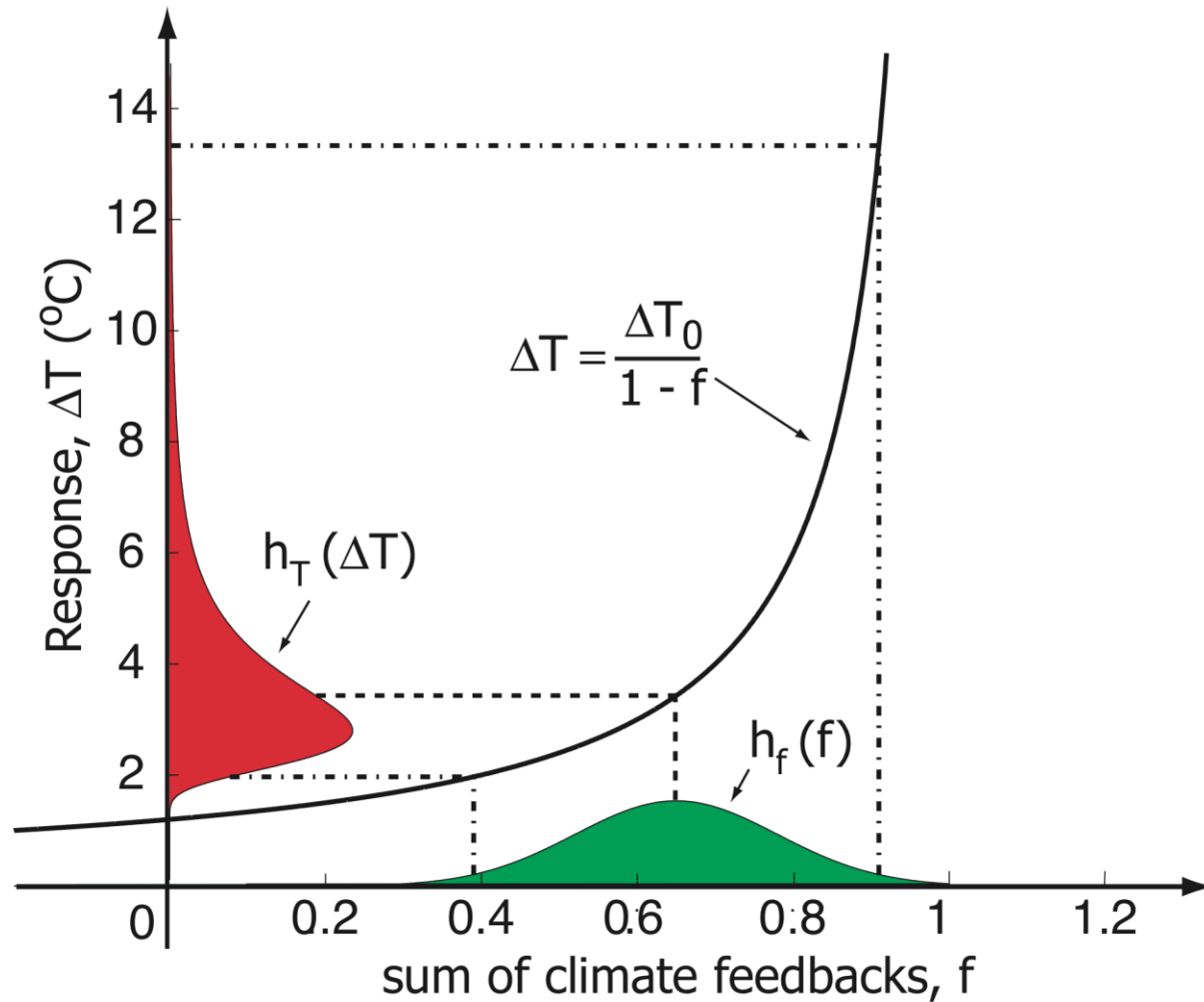
3. Estimates from models



- Red curve is resulting uncertainty in climate sensitivity.

Climate sensitivity

3. Estimates from models



- Red curve is resulting uncertainty in climate sensitivity.

Climate sensitivity

4. Prospects for progress

a. Improved observations/models

Its hard!! Incremental improvements, but probably no breakthroughs.

b. Combine different estimates?

Very hard to establish the degree of independence of individual estimates. (see Knutti and Hegerl, 2008)

c. Use other observations?

(e.g., NH vs. SH; pole-to-eq. ΔT ; seasonality, trop. water vapor)

Structural errors among models highly uncertain. (see Knutti et al, 2010)

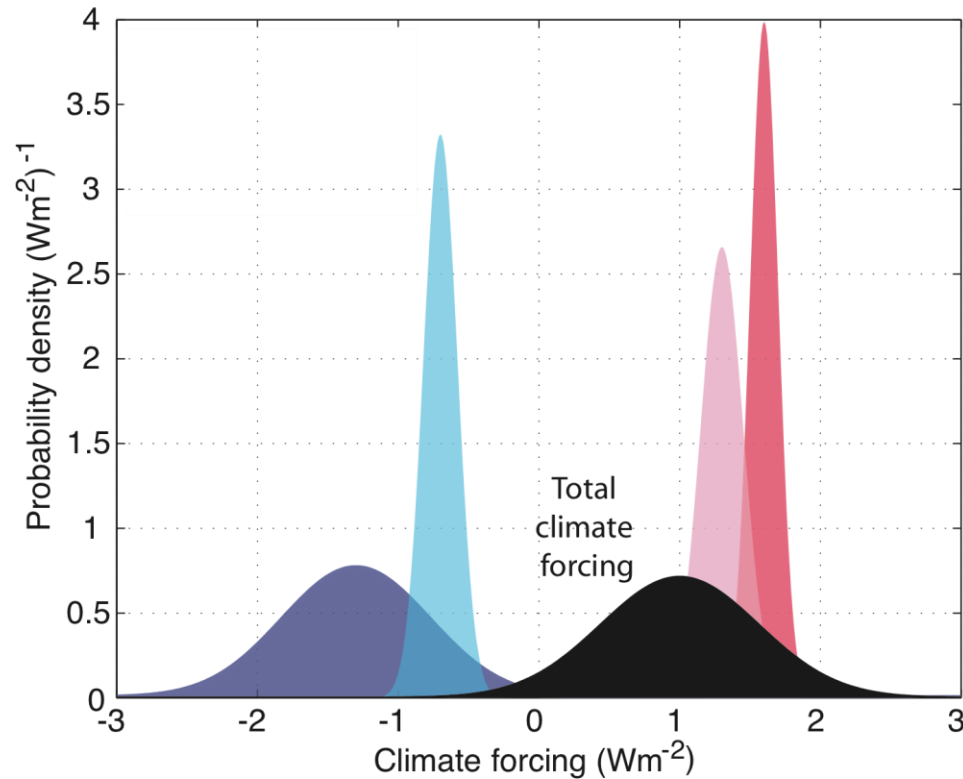
➔ Prudent not to expect big improvements any time soon....

Climate commitment

1. What if all anthropogenic emissions ceased tomorrow?

Lifetimes: CO₂: centuries to 100,000 yrs+

Aerosols: days to weeks

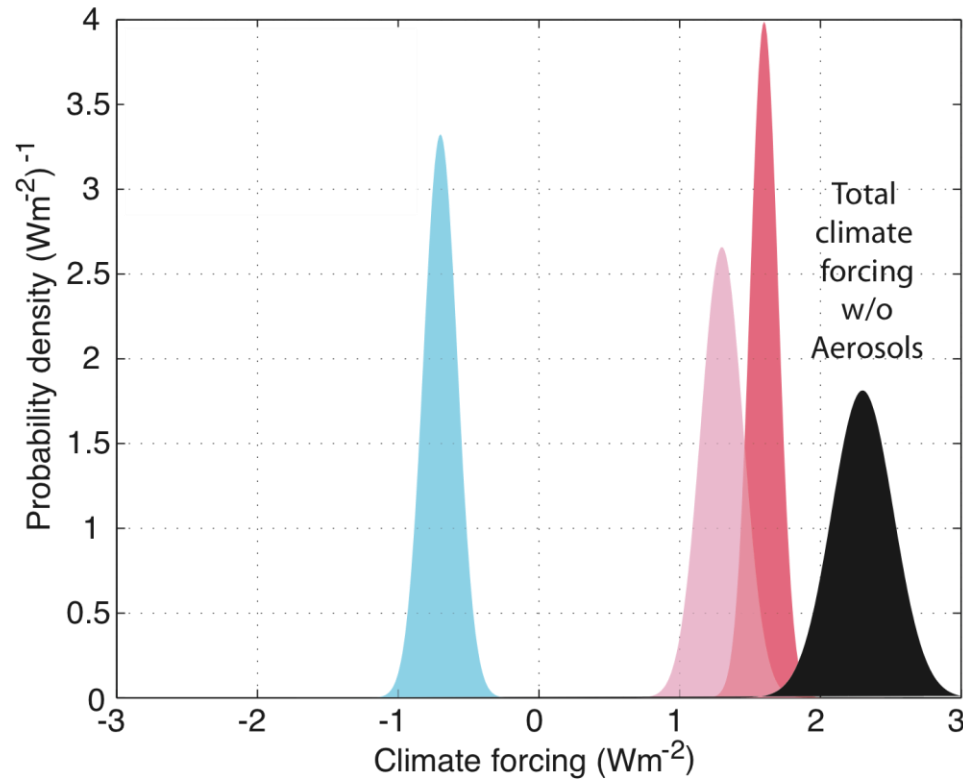


Climate commitment

1. What's already in store for us?

Lifetimes: CO₂: centuries to 100,000 yrs+

Aerosols: days to weeks

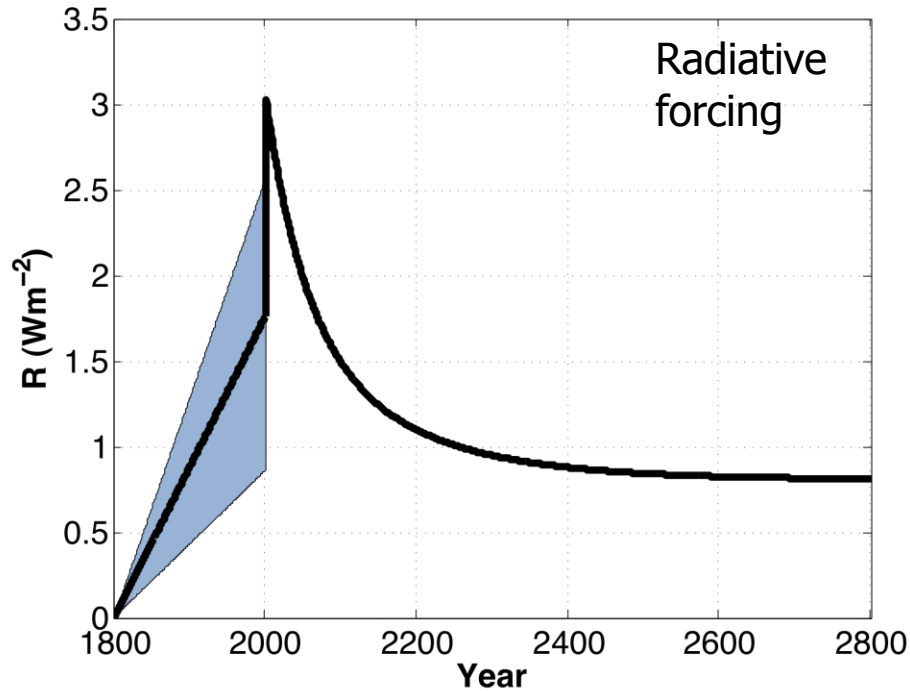


- Immediate loss of aerosols *unmasks* GHG gas warming

Climate commitment

1. What's already in store for us?

Idealized timeline of past and future climate forcing, if we stop everything today



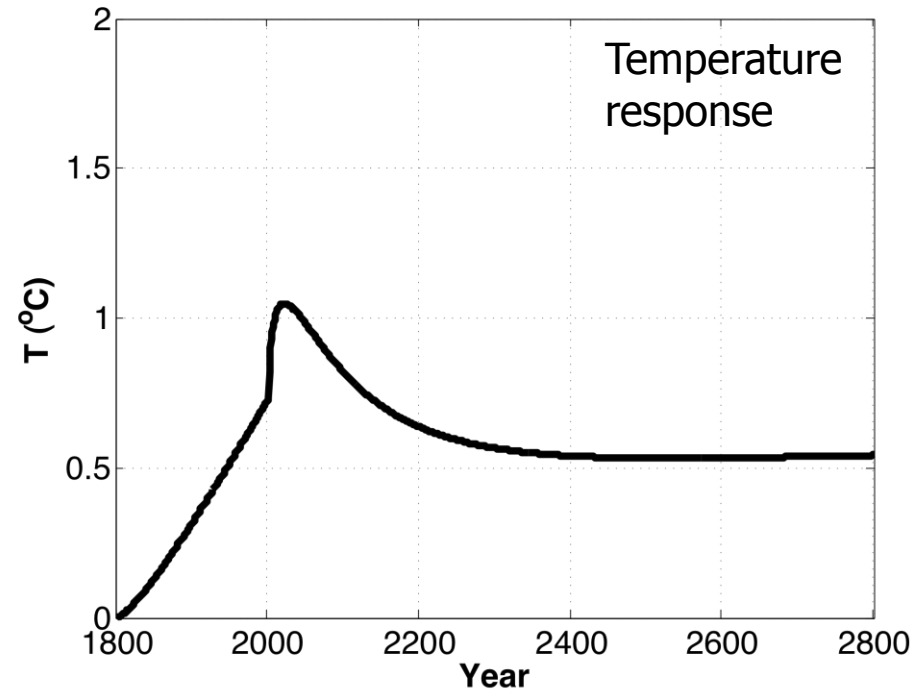
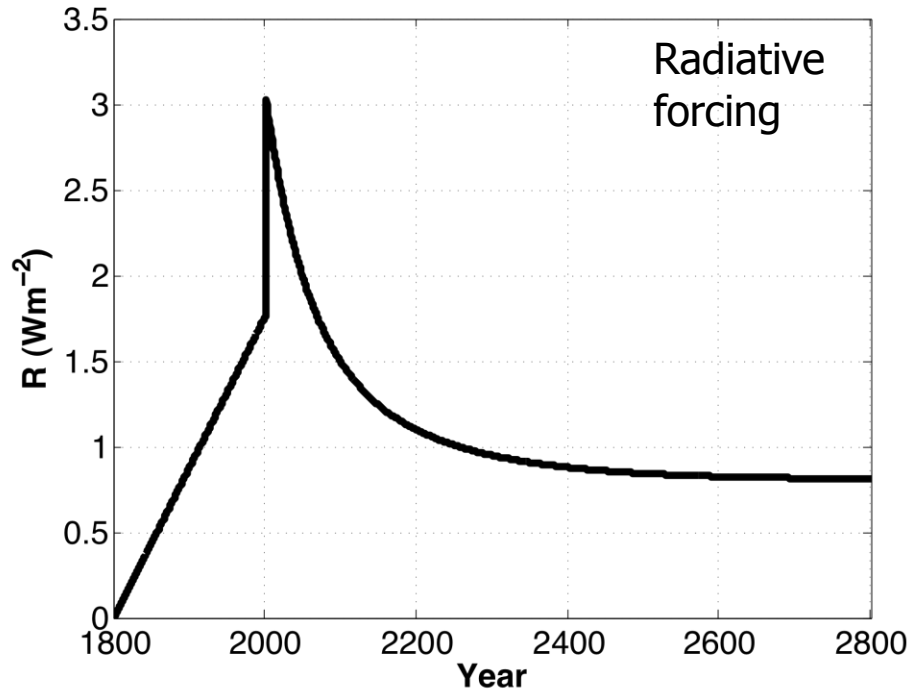
What does
the
climate do?

90% error bounds,
IPCC numbers,
(Kyle Armour)

Climate commitment

1. What's already in store for us?

Our best guess at what would happen

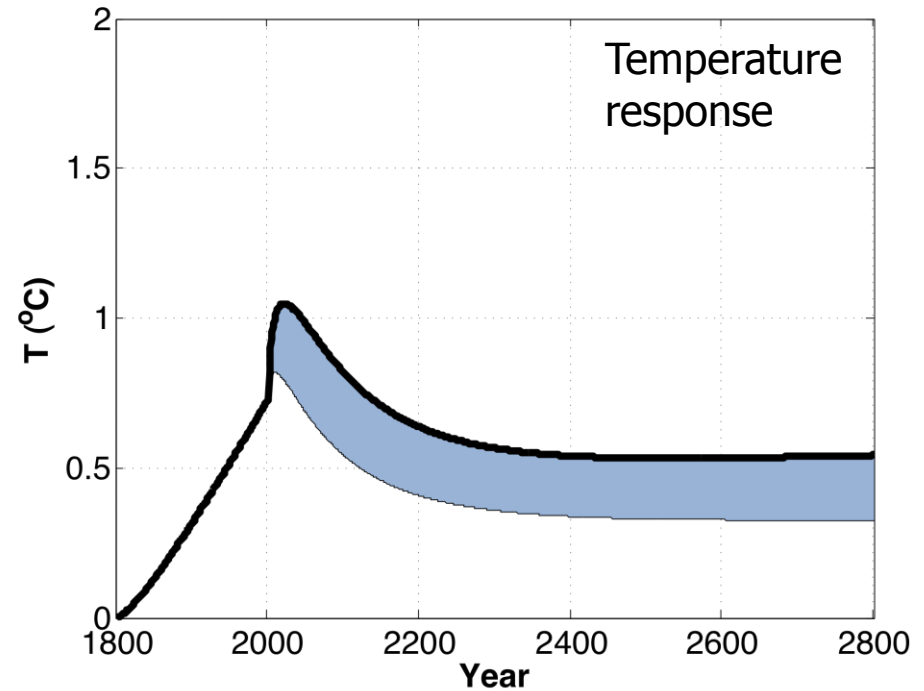
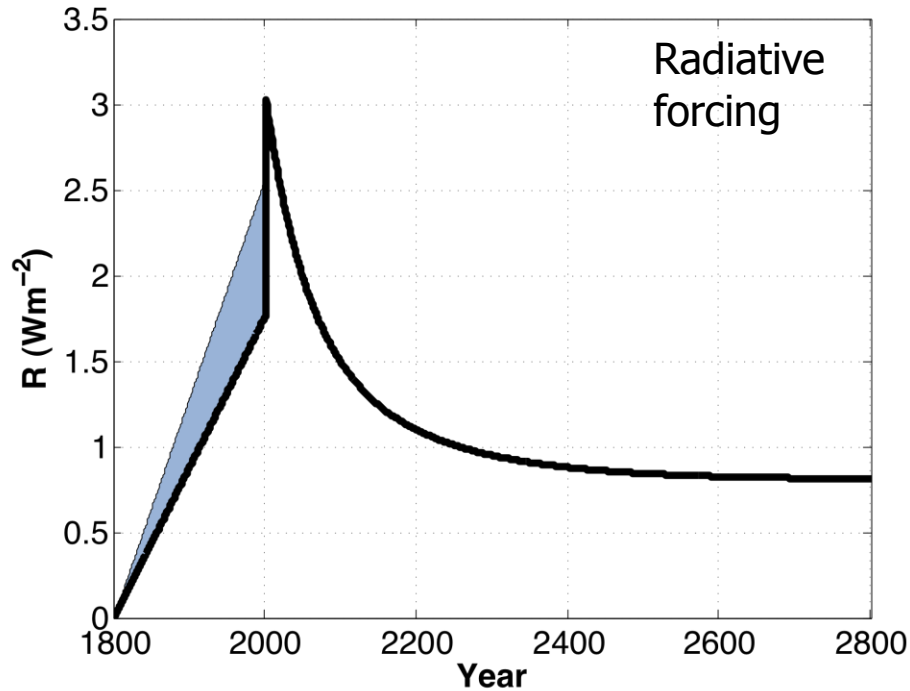


90% error bounds,
IPCC numbers,
(Kyle Armour)

Climate commitment

1. What's already in store for us?

But if past forcing has been high....

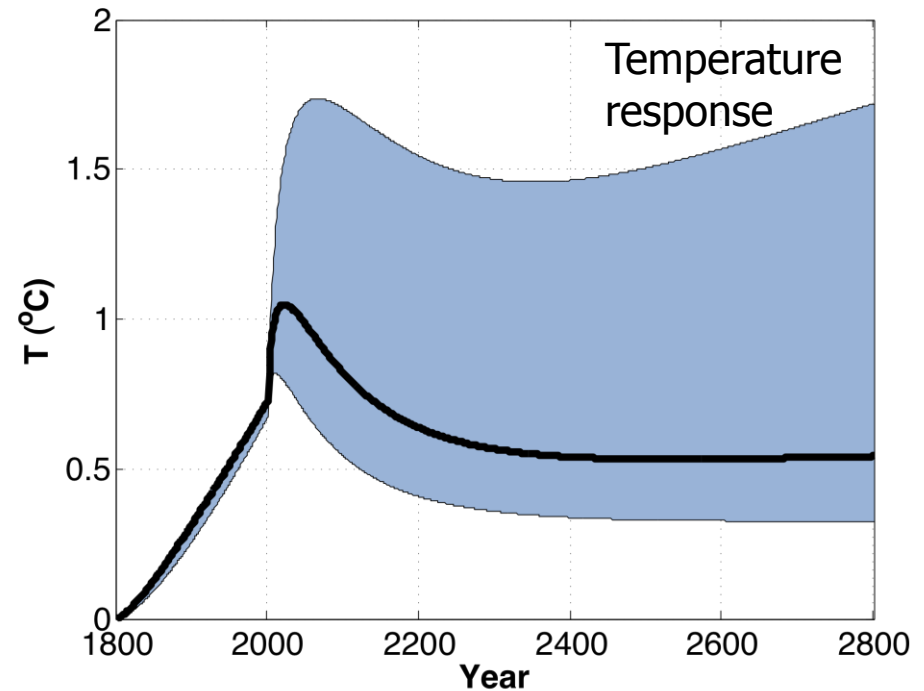
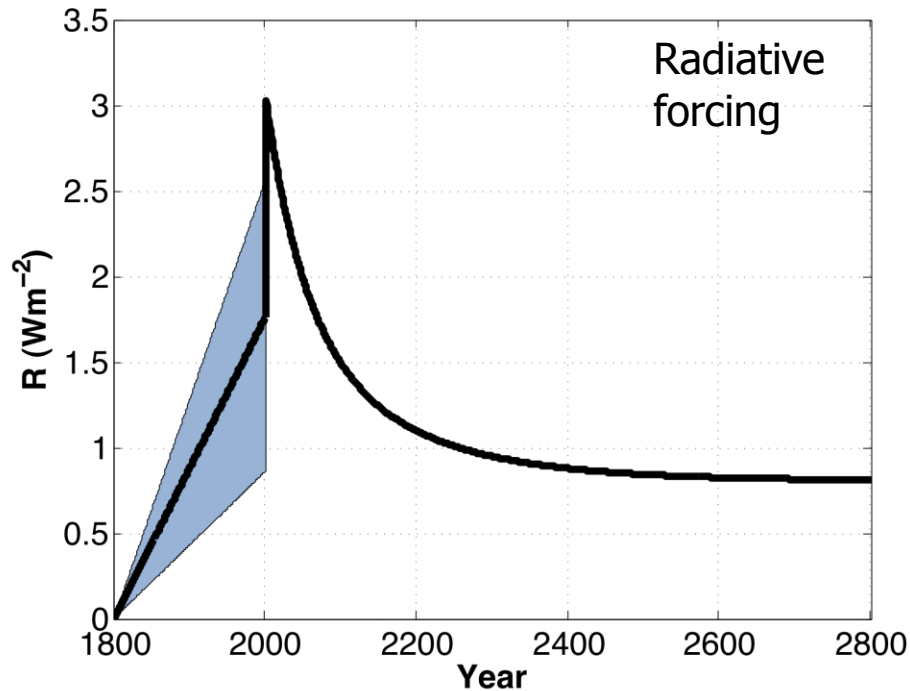


90% error bounds,
IPCC numbers,
(Kyle Armour)

Climate commitment

1. What's already in store for us?

But if past forcing has been low....



90% error bounds,
IPCC numbers,
(Kyle Armour)

Climate commitment

2. Past forcing and climate sensitivity are intrinsically related

If past forcing is strong → climate sensitivity is low.

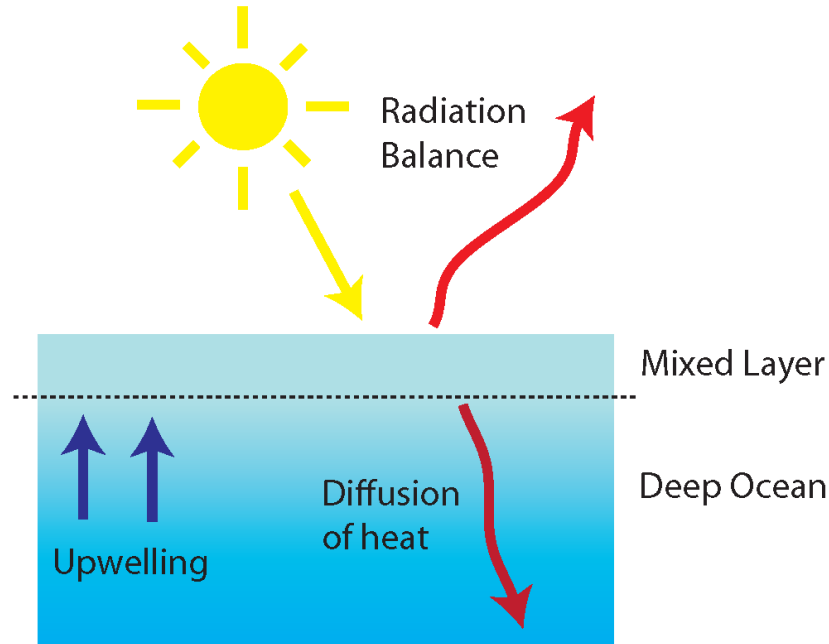
If past forcing is weak → climate sensitivity is high.

For Integrated Assessment Models this matters:

- forcing (including aerosol forcing) cannot be assumed to be independent of climate sensitivity .

Transient evolution of climate

1. Heat uptake of the ocean is diffusive

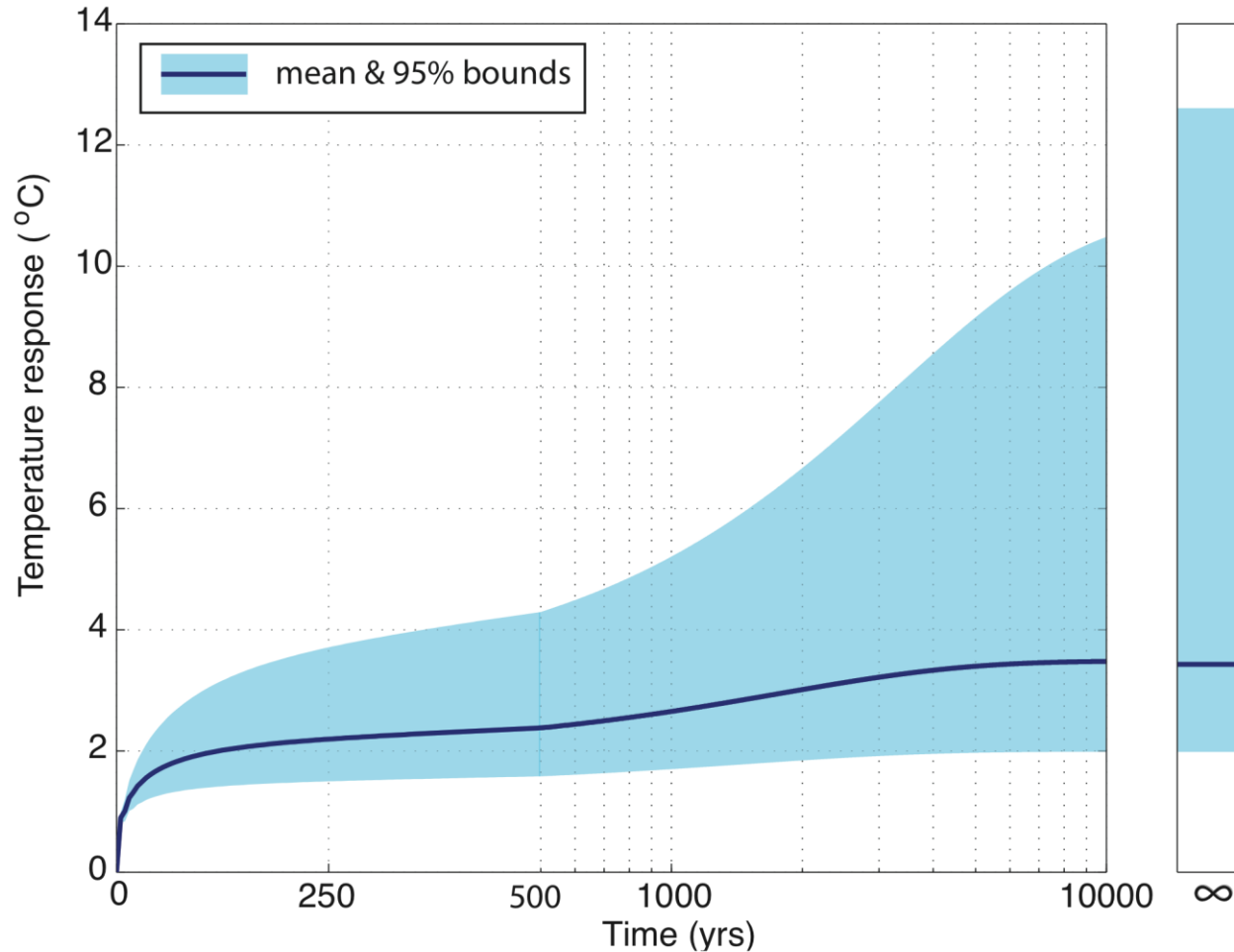


Hansen et al. (1985) show this means that

Climate adjustment time
is proportional to
 $(\text{Climate Sensitivity})^2$

Transient evolution of climate

2. The fat tail grows very slowly

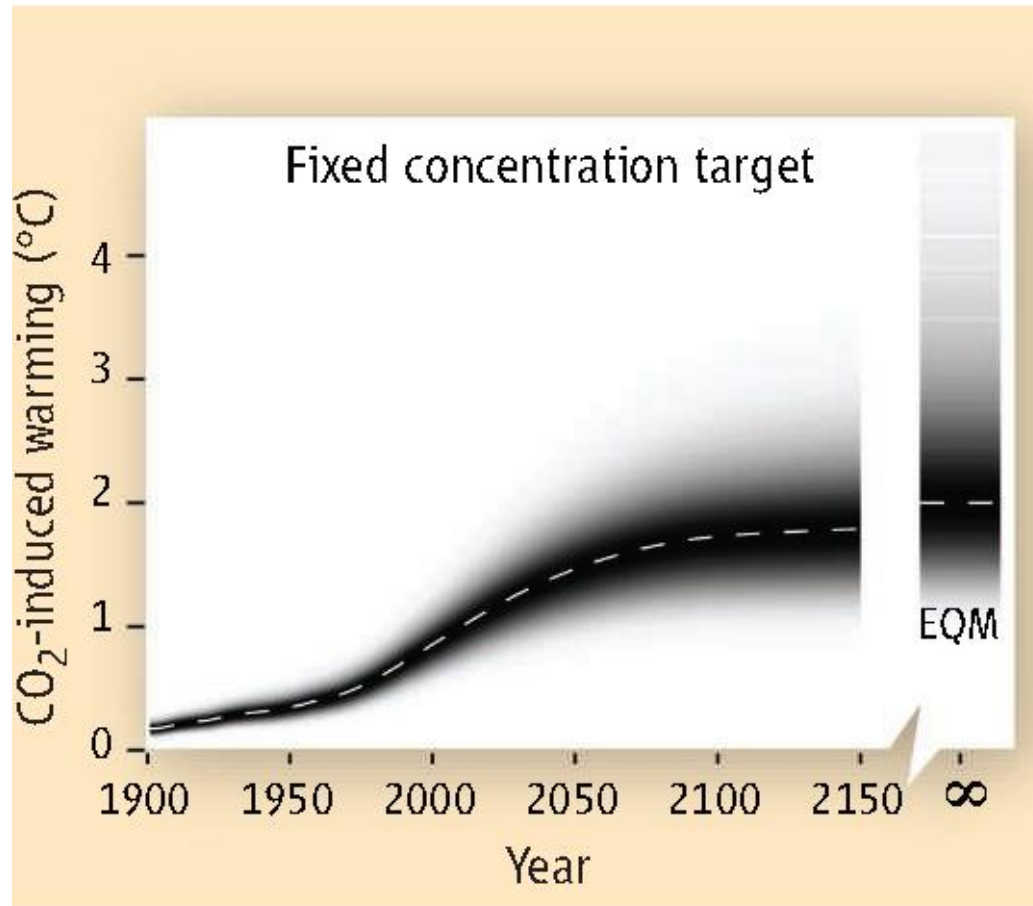


climate model response
(mean & 95% bounds)
to an instantaneous
doubling of CO₂

- Constraining the details of the far tail of climate sensitivity is not useful on societally relevant timescales?

CO₂ stabilization targets are a mistake

1. Climate response to fixed level of CO₂ is uncertain



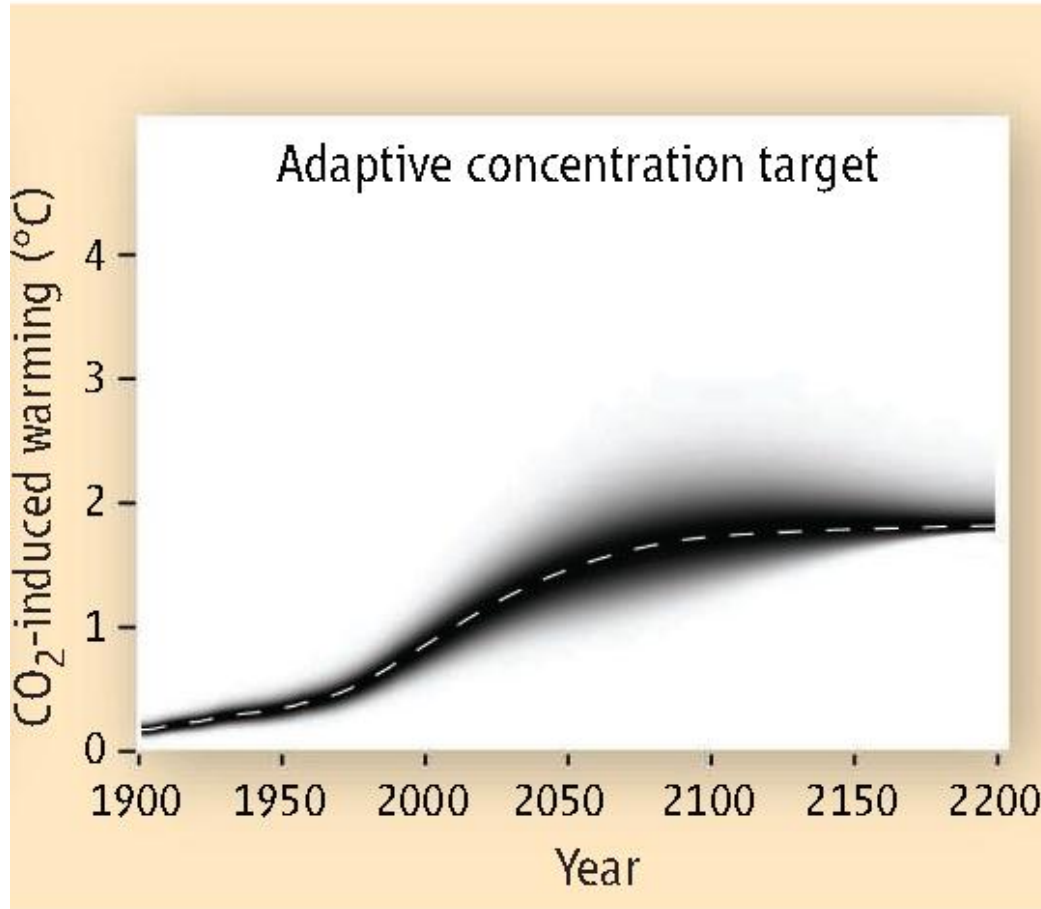
(Allen and Frame, 2007)

Stabilization target
of 450 ppm at 2100

- High end sensitivities take a long, long time to be realized
- There is still considerable uncertainty at 2150.

CO₂ stabilization targets are a mistake

2. Flexibility is key



(Allen and Frame, 2007)

Concentration
target adjusted
at 2050.

- A flexible emissions strategy is key to reaching a desired goal

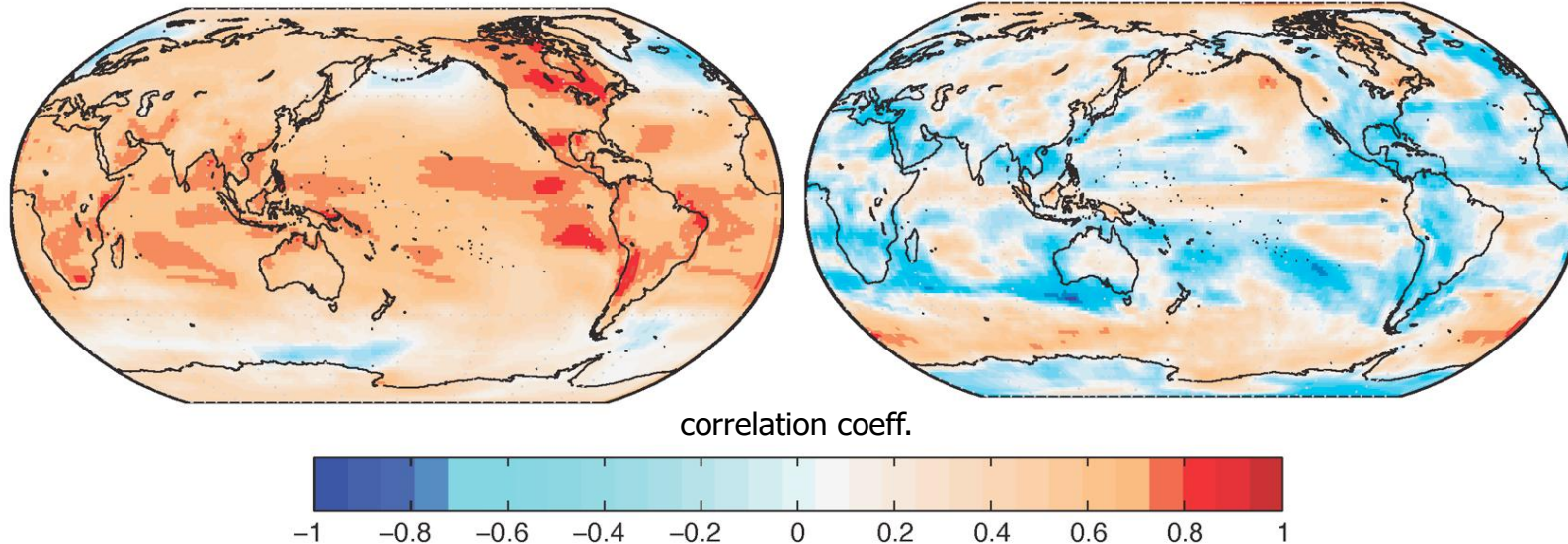
Does global climate predict local climate?

1. Is climate sensitivity a good predictor of regional change?

- Among models, how well are varⁿs in global climate sensitivity correlated with varⁿs in regional climate change at 2100?

Annual mean temperature

Annual mean precipitation



If |corr. coeff.|
< 0.70 then
<50% of local
change is
associated with
global mean
change.

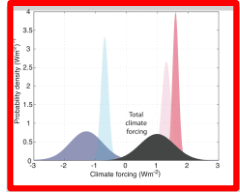
- The magnitude of local changes is affected by many factors
- Global ΔT is quite a poor predictor of local ΔT , ΔP
- If impacts are local, should global ΔT be used to calculate damages?

19 models from IPCC
2007 report,
For more calculations
see my web site.
(calcⁿs made by
Nicole Feldl)

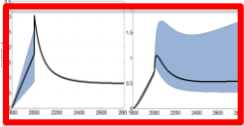
Summary:



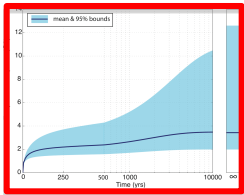
1. Uncertainty is not ignorance.
The planet is warming and its us that's doing it.



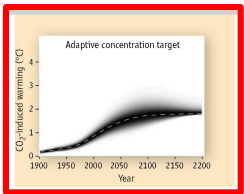
2. Climate sensitivity is uncertain b/c past forcing is uncertain (primarily aerosols).



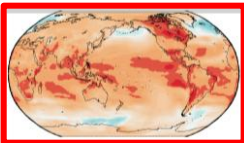
3. Uncertainty in climate sensitivity and climate forcing are not independent.



4. If climate sensitivity is high, it takes a very long time to get there.

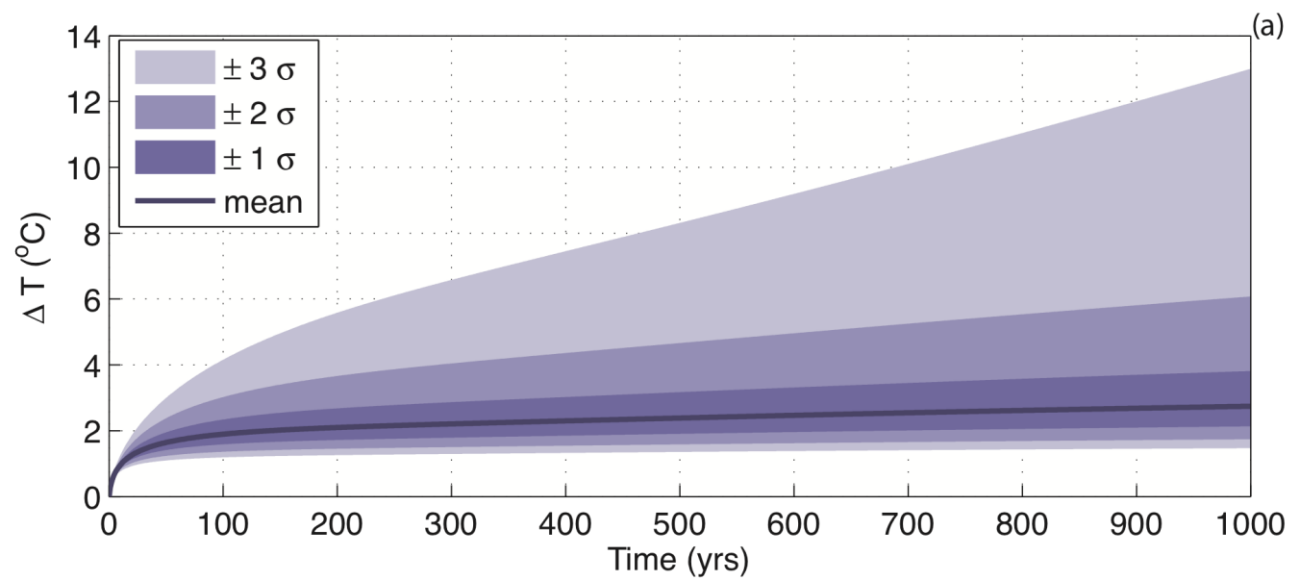


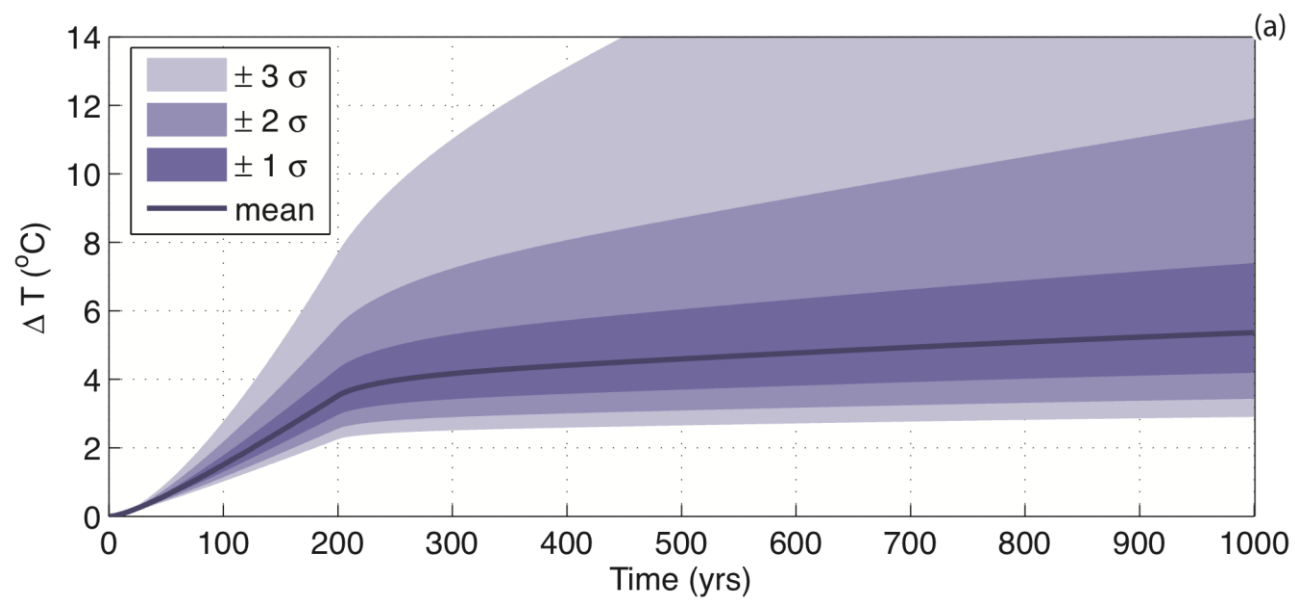
5. CO₂ stabilization targets are not an efficient way to achieve a climate goal. (flexibility is vital)



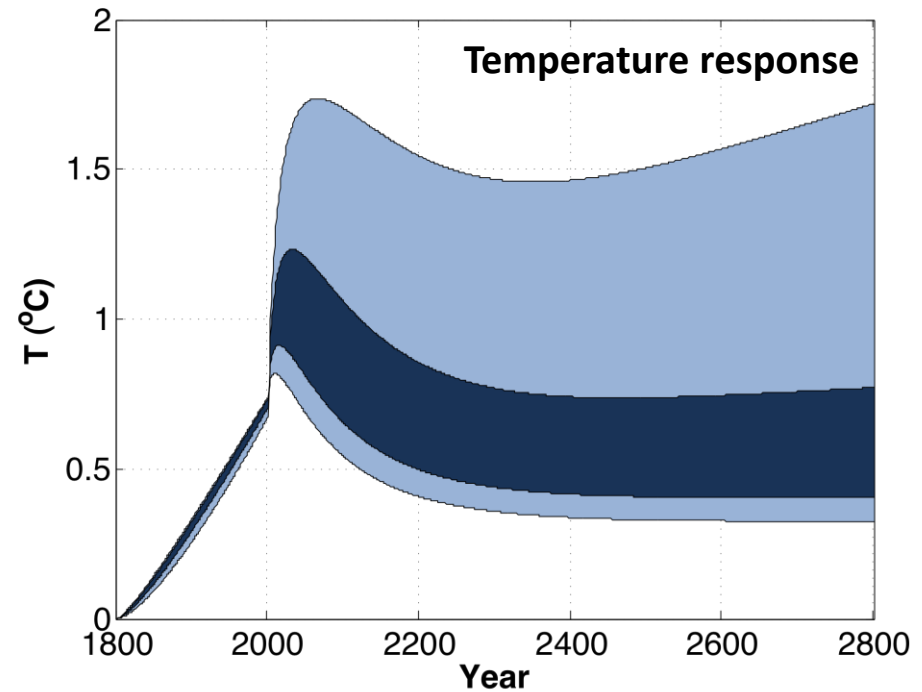
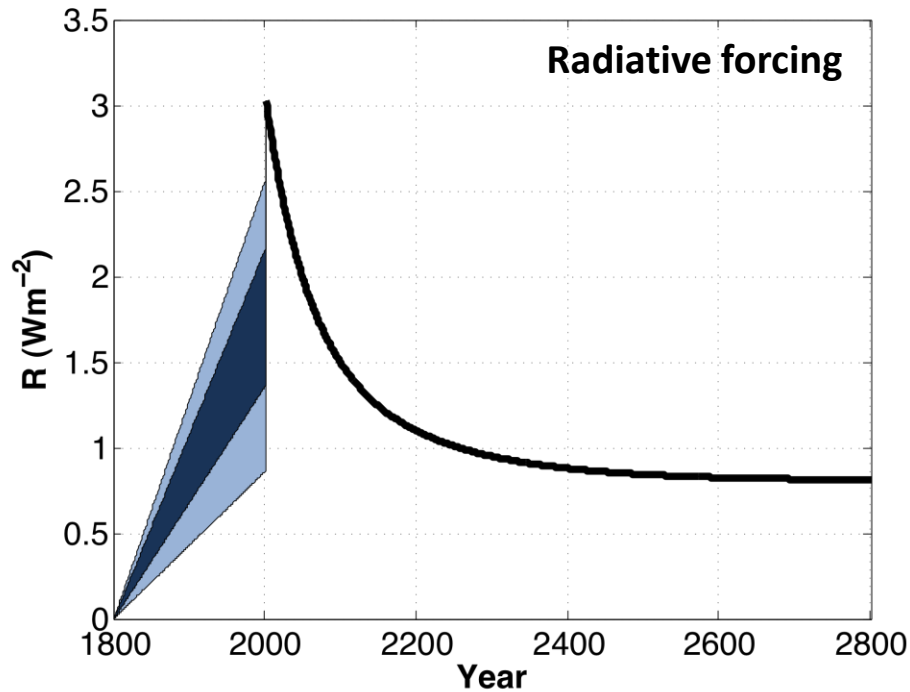
6. Global climate is not a strong predictor of local climate change.

Extra slides....



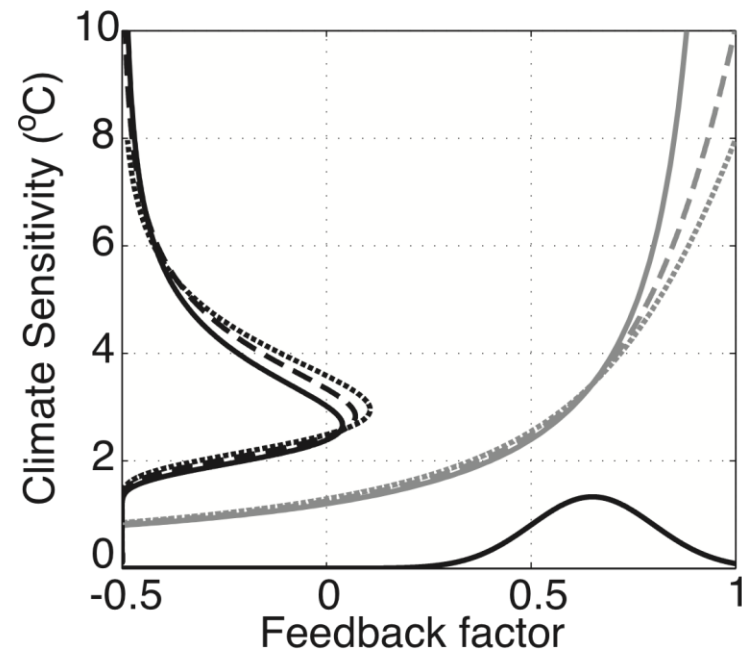
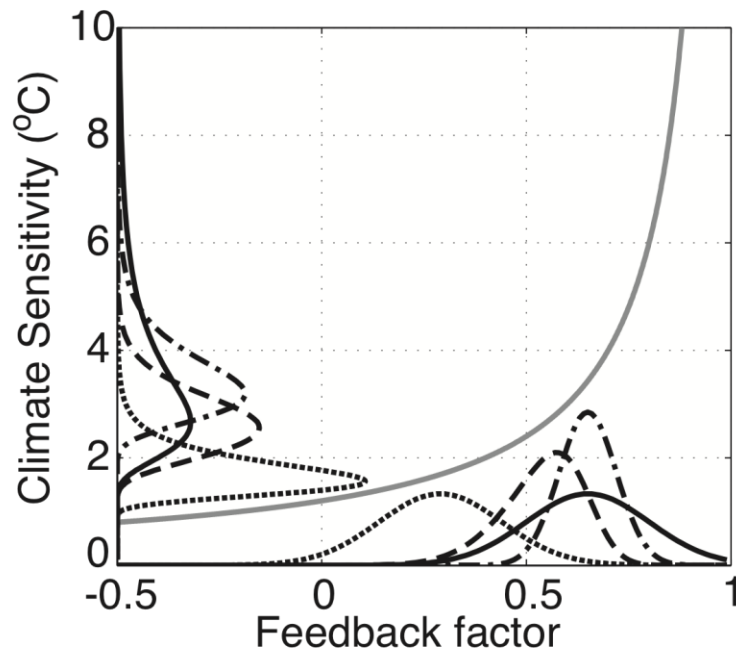


AR4 models undersample climate commitment

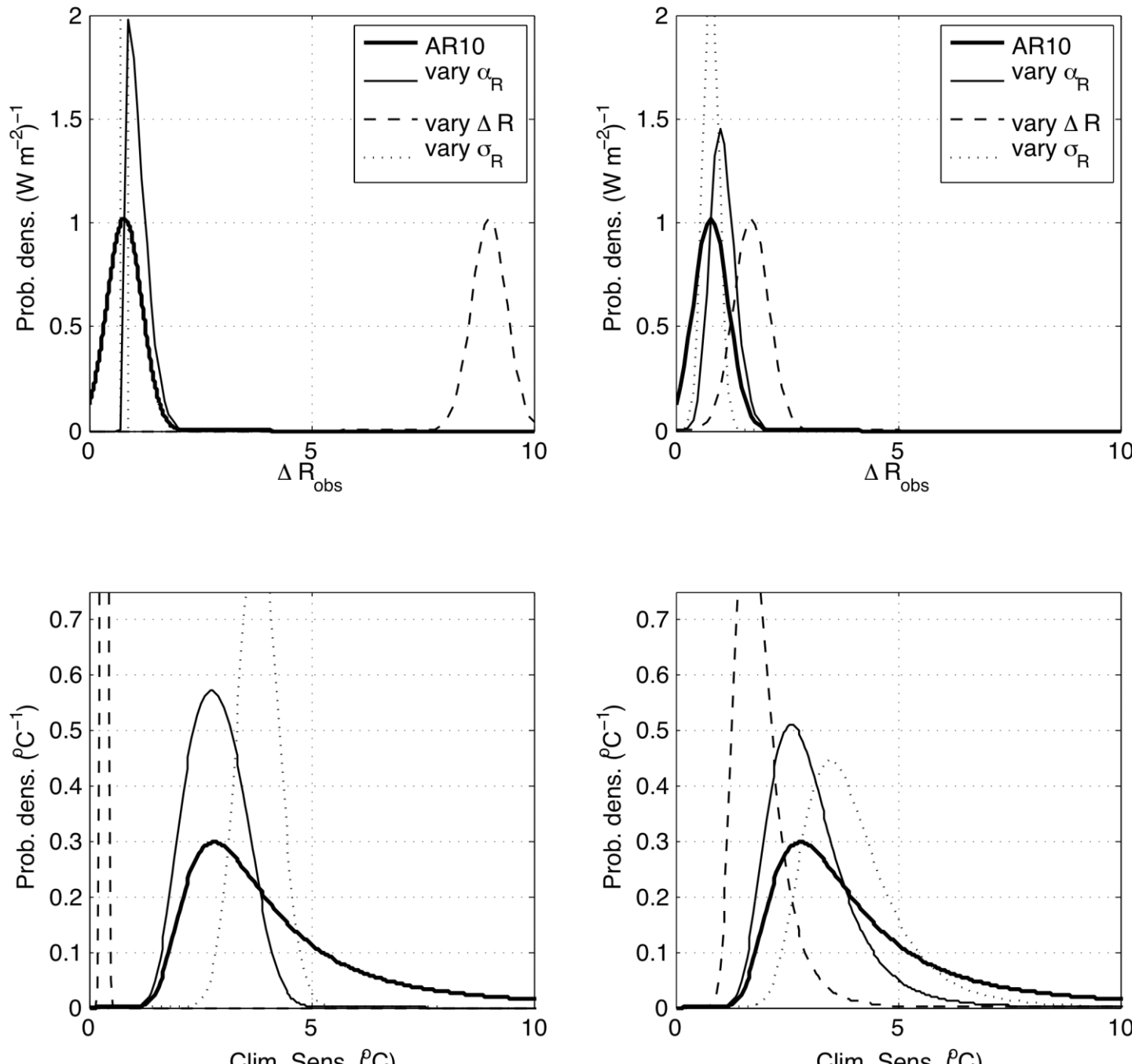


- Dark blue is the IPCC 'likely' (68% confidence interval) range of climate sensitivity (2 to 4.5 C) and implied range of radiative forcing
- AR4 climate models span only this 'likely' range
- R and λ are correlated within AR4 and older models (Kiehl 2007, Knutti 2008)

Effects of nonlinearity of climate feedbacks

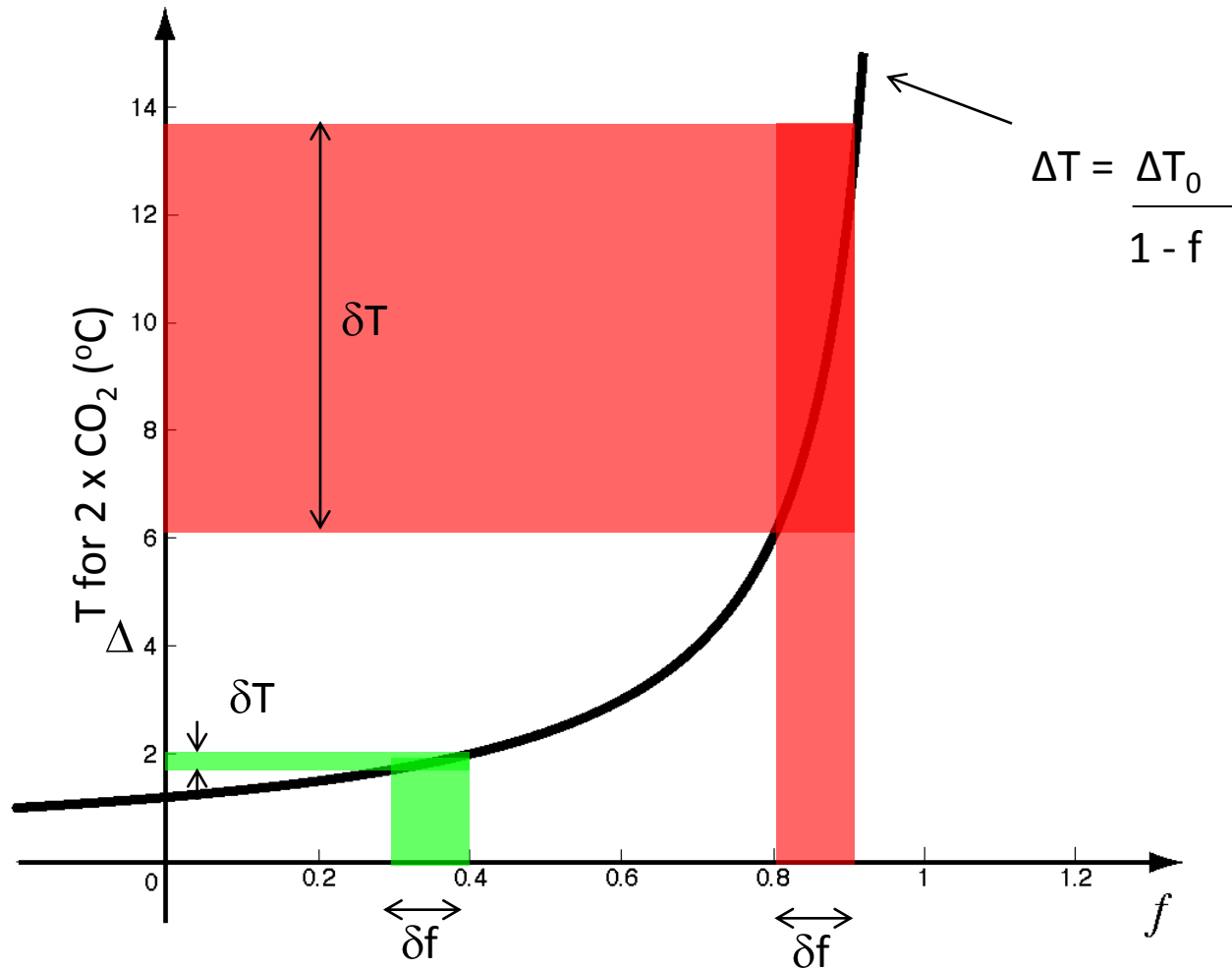


By how much do observations have to change to change climate sensitivity



Aspects of feedbacks III.

How does uncertainty in feedbacks translate into uncertainty in the system response?



Systems of strong positive feedbacks inherently less predictable